

A correlation of air plethysmography and color-flow-assisted duplex scanning in the quantification of chronic venous insufficiency

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Purpose: Air plethysmography has been useful in assessing patients who have chronic venous insufficiency. Limb reflux times determined by color-flow-assisted duplex scanning have been shown to correlate with the severity of chronic venous insufficiency. The purpose of this study was to compare air plethysmographic measurements with reflux times obtained by color-flow-assisted duplex scanning in patients with chronic venous insufficiency.

Methods: One hundred twenty-two limbs in 61 consecutive patients with various stages of chronic venous insufficiency were evaluated; air plethysmographic and color-flow-assisted duplex scans were performed at the same sitting. Fifty-nine of the patients had venous ulceration. Values obtained by air plethysmographic scans included venous filling index, ejection volume, residual volume, ejection fraction, and residual volume fraction. Color-flow-assisted duplex scan values included reflux times in the deep and superficial venous segments and total and mean limb reflux times.

Results: Using the Pearson correlation, the venous filling index was found to correlate significantly with total limb venous reflux times, mean total limb reflux times, and venous reflux times in the deep venous system, as determined by color-flow-assisted duplex scans ($p < 0.001$).

Conclusions: Limb reflux time as determined by color-flow-assisted duplex scans correlated significantly with the air plethysmographic variable accepted as a measure of the severity of venous reflux, the venous filling index. This study confirms the validity of total limb reflux times in the quantification of chronic venous insufficiency. (*J Vasc Surg* 1996;24:750-4.)

Chronic leg venous hypertension, which leads to progressive venous stasis changes and in some patients to frank ulceration, may be the result of many factors. These factors include primary valvular insufficiency, secondary valvular insufficiency as a result of deep venous thrombosis or trauma, venous outflow obstruction, or combinations of these entities. Invasive determination of ambulatory venous pressure has been the standard for the quantitative assessment of

the severity of venous disease.¹ Quantitative noninvasive assessment of venous hypertension and reflux has been based mostly on hemodynamic measurements involving the entire leg or the limb below the knee.² Using air plethysmography (APG), the venous volume, ejected volume, and residual volume after exercise of the affected limb below the knee may be determined. From these values a venous filling index (VFI), ejection fraction (EF), and residual volume fraction (RVF) are calculated.³ Each of these hemodynamic values has been correlated with the severity of the venous disease. Increasing values of VFI that reflect the amount of reflux have been associated with progressive clinical signs of chronic venous insufficiency (CVI).⁴ A decrease in EF can be directly related to a decrease in the efficiency of the calf muscle pump and inversely is associated with the appearance of the clinical signs of CVI.⁵ The RVF, a function of the additive effects of abnormal valve reflux and calf pump

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failure, has been found to have a linear correlation with ambulatory venous pressure.⁶

Duplex scanning augmented by color-flow Doppler scanning (CFDS) of the leg venous system performed in patients who have CVI provides anatomic and functional data regarding the contribution of the deep and superficial systems, as well as individual venous segments within each system, to CVI.⁷ Spectral analysis of blood flow in a segment of vein with reflux allows quantification of the extent of the reflux.^{8,9} Using CFDS, we have previously reported that total limb reflux times and deep venous system reflux times correlate with the severity of venous disease and predict venous ulceration.¹⁰

The purpose of this study was to compare hemodynamic data obtained by APG with anatomic and functional data obtained by CFDS in a group of patients in whom various stages of symptomatic CVI were diagnosed, including those who had long-standing venous ulceration.

PATIENTS AND METHODS

A comparative analysis of two different methods used in the quantification of chronic venous reflux was performed. A series of 122 limbs in 61 consecutive patients was used in the analysis. All patients initially had symptomatic CVI (CVI 1 and 2) or chronic venous ulceration (CVI 3). The severity of the disease was categorized according to the classification criteria published by the Society for Vascular Surgery and International Society for Cardiovascular Surgery.¹¹ All patients in whom unilateral venous ulceration was diagnosed had evidence of CVI 1 or 2 in the contralateral limb. The 29 women in the study had a mean age of 57 years (range, 31 to 89 years), and the 32 men had a mean age of 55 years (range, 28 to 80 years). Patients who had evidence of significant arterial obstruction were excluded. Patients whose pedal pulses were not palpable were included if ankle-brachial indexes greater than 0.75 or toe-brachial indexes greater than 0.6 were obtained. Patients who were not able to balance on one limb for the CFDS part of the examination and those patients who were unable to perform toe-raises as part of APG evaluation were also excluded. Two patients each had a limb excluded from the series because of technical problems during testing.

CFDS was performed with the Acuson 128XP duplex scanner and the 538 MHz probe (Acuson, Mountain View, Calif.). Scanning of the deep and superficial systems was first performed with the patient in the supine position and with standard techniques to detect totally or partially occlusive venous

thrombosis.^{12,13} Examination of the venous system for reflux was then performed with the patient standing upright and bearing no weight on the leg being studied. Rapid cuff deflation was used to mimic muscle relaxation and to induce reflux. The technique of vein interrogation after cuff deflation has been previously described by us.¹⁴ Visualization of the profunda femoris vein and perforator veins was not possible in every case; the data from these venous segments were excluded from the study. Reflux time intervals were then added: (1) for all segments, which produced a total-limb reflux time (R_t); (2) for only the deep venous system segments, which produced a total-limb deep-segment reflux time (R_{td}); and (3) for only the superficial system segments, which produced a total-limb superficial-segment reflux time (R_{ts}). Reflux times were then averaged: (1) for all segments, which produced a mean total-limb reflux time (M_t); (2) for only the deep system segments, which produced a mean total-limb deep-segment reflux time (M_{td}); and (3) for only the superficial venous segments, which produced a mean total-limb superficial-segment reflux time (M_{ts}). Strict protocols, which were previously described by us,¹⁴ were followed in performing these measurements to minimize inter-rater error.

APG measurements were performed in each subject's limbs using APG Model 1000 (ACI Medical Inc., Sun Valley, Calif.) immediately after the completion of CFDS. Standard protocols were followed in APG measurements.¹⁵ The parameters measured included venous volume on standing (VV), ejection volume after one tiptoe-raise (EV), and the residual volume of the limb after 10 tiptoe-raises (RV). From these measurements three ratios were calculated in the standard fashion: the VFI, the EF, and the RVF. A superficial occluder was used to measure volume changes in the isolated deep venous system, including VV_{so} , EV_{so} , and RV_{so} , and three ratios reflecting the deep system were calculated: VFI_{so} , EF_{so} , and RVF_{so} .¹⁵

Every effort was made to insure interclinician consistency; all limbs were assessed by the same two technologists, and study interpretations were performed by a single physician. The six continuous variables, which were determined by CFDS as previously described, were correlated with the six hemodynamic variables determined by APG. All continuous variables were assessed for departures from normality by obtaining a skewness coefficient and exploring a normal probability plot for each variable.¹⁶ By these criteria, all continuous variables demonstrated acceptably normal distributions and

Table I. Pearson bivariate correlation coefficients comparing CFDS and APG measurements

	APG		
	VFI	EF	RVF
CFDS			
R _t	0.43*	-0.12	0.18
R _{td}	0.36*	-0.12	0.14
R _{ts}	0.35*	-0.08	0.15
M _t	0.43*	-0.13	0.18*
M _{td}	0.37*	-0.12	0.14
M _{ts}	0.35*	-0.08	0.16

*Denotes a significant correlation where 1.00 and -1.00 are perfect correlations.

could be most confidently used with parametric statistical tests.

In an exploratory analysis, the six hemodynamic variables that were determined by APG were correlated with the six continuous variables that were determined by CFDS. These 12 variables were cross-tabulated to produce scatterplot matrixes with 0.50 bivariate ellipsoids.¹⁷ Pearson correlation coefficients and their accompanying *p* values to test for linear association were then calculated to confirm quantitatively the scatterplot matrixes.

The 12 continuous variables as determined by APG and CFDS were then individually tested for their ability to predict chronic venous ulceration (CVI 3). Student's *t* test was used to compare mean values between limbs that had venous ulceration and those that did not. Both ulcerated and nonulcerated samples were large enough to assume unequal variances in performing Student's *t* test.

A *p* value less than or equal to 0.05 was taken to be significant throughout this study. Data were managed and analyzed using SPSS for Windows release 6.0 (1993 SPSS Inc, Chicago, Ill.).

RESULTS

Long-standing venous ulceration of at least one leg or symptomatic CVI had been previously diagnosed in all patients. Fifty-nine limbs (48.4%) in this cohort had venous ulceration. Of the 59 limbs that had CVI 3, 10 (16.9%) had no reflux demonstrated by CFDS. Twenty-nine of the 120 limbs (34.7%) that had CVI 1 or 2 had no evidence of venous reflux on CFDS. Of the 81 limbs that had demonstrable reflux by CFDS, 31 (38.3%) had reflux in an isolated venous segment. In this subset of limbs, reflux was found most commonly in the popliteal vein (15 limbs; 18.5%), the greater saphenous vein (seven limbs;

8.6%), and the lesser saphenous vein (six limbs; 7.4%). Venous obstruction was not identified in any of the limbs that we studied.

The Pearson bivariate correlation coefficients for the VFI with the CFDS parameters ranged from 0.35 to 0.43 (Table I). The VFI was the only APG measurement that correlated significantly with all six CFDS parameters (*p* < 0.001). EF and RVF did not significantly correlate with the CFDS parameters, except in the case of M_t and RVF (*p* < 0.05; see Table I). Correlation of APG parameters VFI_{so} and RVF_{so} with all six CFDS parameters demonstrated no changes in Pearson correlation coefficients compared with the VFI and the RVF. A comparison of EF and EF_{so} with all six CFDS variables, on the other hand, revealed that R_{td} and M_{td} significantly correlated with only EF_{so}, not EF (*p* < 0.01).

In comparing ulcerated and nonulcerated limbs, both RVF and VFI demonstrated significantly different means (*p* < 0.05). The mean VFI for limbs with CVI 3 was 4.25 seconds, whereas the VFI in limbs that exhibited CVI 1 or 2 was 3.18 seconds. The RVF for the CVI class 3 limbs was 43.0%, whereas the RVF for limbs in CVI class 1 and 2 was 31.4%. A higher RVF and a higher VFI corresponded with the presence of ulceration in this cohort. Among the CFDS parameters, R_t and R_{td} also demonstrated a significant difference in means when comparing CVI class 3 limbs with limbs in classes CVI 1 and 2 (Table II).

DISCUSSION

APG has proved to be a simple and reproducible method of evaluating leg venous hemodynamics. VFI measurements are a direct reflection of the severity of valvular reflux.⁶ VFI measurements of 2 ml/sec or less signify an absence of significant valvular reflux and slow filling of the venous system from arterial inflow. A VFI greater than 7 ml/sec is associated with a high incidence of CVI¹⁵ and can be used to distinguish the hemodynamic state of the asymptomatic from the ulcerated limb.¹⁸ VFI compares favorably with descending venography in the detection of significant reflux.¹⁹ The other parameters measured by APG, including EF and RVF, have proved useful in assessing calf muscle function and valvular incompetence.^{3,20-21}

Visualization of individual venous segments, using duplex scanning and spectral analysis to quantify the extent of reflux, has been described by several authors. With spectral analysis, flow at peak reflux in ml/sec has been found to correlate with the presence of lipodermatosclerosis and ulceration.⁸

Using a technique of measuring venous reflux times that was originally described by van Bem-

melen,^{9,22} in a previous study we measured reflux times in a series of patients who had varying degrees of CVI. R_t (the summation of the reflux times of all the segments evaluated in the limb) and M_t (mean total-limb reflux time) were found to correlate with the severity of CVI. An R_t value greater than 9.66 seconds was predictive of venous ulceration in this study.¹⁰ Quantitative reflux data obtained by other laboratories has been found to be more predictive of the severity of CVI than descending venography.²³

CFDS as performed in this study did not attempt to visualize the entire venous system of the limb. Visualization and quantification of venous reflux in the anterior tibial vein were not performed. The iliac, profunda femoris, and perforating venous segments could not be reliably interrogated and were also not included in this study. This may account for the finding that of the limbs in class CVI 3, 16.9% showed no reflux by CFDS, and 34.7% of limbs in class 1 or 2 failed to show venous reflux. These observations were similar to those previously reported by this laboratory.¹⁰

Information obtained from APG and CFDS appear to be complementary. APG provides hemodynamic data on valvular reflux and calf pump function, whereas duplex scanning provides anatomic detail on segmental reflux and obstruction. Neglén and Raju²⁴ have indicated that only the combined measurements of reflux as determined by CFDS and the VFI as determined by APG are predictive of the severity of venous disease. Bays et al.²⁵ found that all invasive tests for venous insufficiency could be eliminated with a combination of APG hemodynamic information and anatomic data as visualized by CFDS.

Studies that have attempted to find a correlation between the APG and CFDS data have been based on comparisons of different hemodynamic parameters that are obtained by APG and the anatomic measurements (size of the veins) or the categorical variables (presence or absence of reflux) that are determined by CFDS. van Bemmelen and colleagues²⁶ compared VFI values with duplex measurements of vein diameters and found that VFI correlated somewhat with the diameter of lower leg veins and that the total leg venous volume correlated moderately well with calf-vein diameter. Payne and colleagues²⁷ compared the 90% venous filling time (VFT_{90}), VFI, and RVF as determined by APG with the presence or absence of significant reflux in the popliteal vein as determined by duplex scanning. Significant reflux was defined as a reflux duration greater than 0.5 seconds. The presence of popliteal vein reflux was associated significantly with an in-

Table II. Reflux times (in seconds)

<i>Reflux times</i>	<i>CVI 1 and 2</i>	<i>CVI 3</i>
Mean R_t	4.00 ± 5.93	6.20 ± 6.31
Mean R_{TD}	1.91 ± 3.34	3.51 ± 4.20
Mean R_{TS}	2.06 ± 3.96	2.70 ± 3.19

crease in the rate of reflux as measured by VFI and a shorter VFT_{90} . The RVF values could not be used to distinguish between limbs that had significant popliteal vein reflux and those that did not.²⁷

The objective of this study was to compare the quantitative data that was obtained by CFDS in the form of continuous variables (limb reflux times) with the hemodynamic continuous variables that were produced by APG. In this study, VFI as determined by APG correlated significantly with all CFDS parameters. Isolation of the deep system with a superficial occluder did not alter the correlation. In comparing other APG measurements with CFDS, the only significant correlation was between RVF and M_t . The association of an APG measurement of venous valve function with an anatomic and functional measurement of valve reflux time is not surprising. Both parameters have been shown independently to predict the severity of CVI, and both are different methods of measuring valve function. The failure of previous studies to make this connection seems to be based on the fact that they did not use quantitative reflux times to categorize the severity of venous disease. Previous studies used categorical data, which were then compared with APG values, instead of continuous CFDS data in the form of reflux times. In this study, the statistically significant association of continuous CFDS variables with existing APG parameter VFI indicates that a patient with a CFDS score indicative of severe CVI would be expected to be categorized as having severe CVI on the basis of APG testing.²⁸

The failure of superficial venous occlusion to change the outcome of the comparisons suggests that most of the reflux comes from the deep system in patients who have both superficial and deep venous reflux. This finding is consistent with our previous report on the importance of the deep system in predicting venous ulceration.¹⁰ Using CFDS data, we found that R_t and R_{td} were significantly associated with venous ulceration, whereas R_{ts} was not. In assessing the individual role of venous segments in predicting the presence of venous ulceration, reflux duration in the common femoral vein and posterior tibial veins correlated the most.¹⁰ More proximal venous reflux would be expected to raise venous

pressure throughout the limb, which would result in a greater tendency to ulcerate. The importance of the posterior tibial vein reflux in CVI and its association with venous ulceration have been stressed by other authors.²⁴ The correlation of RVF and M_t is expected, given that RVF is really a reflection both of venous valve function and of the effectiveness of the calf muscle pump.

The finding that the mean VFI and RVF values in the CVI 3 group were significantly different from the mean values in patients who did not have ulceration is consistent with other reports on the importance of VFI in predicting ulceration and on the association of RVF with ambulatory venous pressure. The importance of venous reflux times in the prediction of ulceration found in this study confirms our findings in a previous study using CFDS.

The use of CFDS in the quantification of venous reflux provides both anatomic and functional information on the role of individual venous segments in CVI. In two separate studies, we have found limb reflux times as determined by CFDS to predict the presence of venous ulceration. In addition, limb reflux times have been found to correlate significantly with APG hemodynamic measurements, which long have been accepted as predictors of the severity of CVI.

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